Source Inversion Validation (SIV)
Quantifying Uncertainties in
Earthquake Source Inversions

Results & Recent Developments

2013 Workshop during SCEC Annual Meeting
Sept 8-11, 2013, Palm Springs
SIV online cooperation platform: equake-rc.info

- Access to input data and relevant information via the SIV wiki:
  - equake-rc.info/sivdb/wiki

- Access current & previous benchmarks:
  - equake-rc.info/SIV or equake-rc.info/SIVsivtools/list_benchmarks

- Participating modelers need to register to upload their solutions
- Passive observers can view and download solutions and related waveforms and figures
- General status seems “healthy” and stable
SIV exercises: status on participation

- Several new participants in the forward-modeling tests
  - Strike-slip extended fault
  - Dip-slip extended fault
- Three groups only that tackled inv2a so far
  - M 7 normal-faulting event; GPS data provided (but not used); some meta-data uncertainty
- No solution to inv2b (similar to inv2a, but with Green’s function uncertainty)
- No further solutions to inv1 (total participants: 6)
- Several additional requests for participation, but most of them have not uploaded anything so far
SIV forward exercise: strike-slip extended fault

- fault dip = 90°; fault strike = 90°
- Fault dimensions: 12 km along-strike, 11 km down-dip
- Seismic moment: $M_0 = 1.658 \times 10^{18}$ Nm ($M_W = 6.11$)
- Hypocenter @ $Z = 14$ km; fault extent $Z = [6 - 17]$ km
- Distributed slip-rate over the fault plane
- Rise time $t_r$, variable over the fault variable
- Rupture times imply non-constant rupture speed
- Uniform source-time function: boxcar of width $t_r$
SIV forward exercise: strike-slip extended fault

- Two solutions: blue COMPSYN / green SORD
SIV forward exercise: strike-slip extended fault

- Two solutions (filtered to 1 Hz): blue COMPSYN / green SORD
SIV forward exercise: dip-slip extended fault

fault dip = 40°; fault strike = 270°
Fault dimensions: **12 km along-strike, 12 km down-dip**
Seismic moment: \( M_0 = 1.824 \times 10^{18} \text{Nm} \) (\( M_w = 6.14 \))
Hypocenter @ \( Z = 9.5 \text{ km} \); fault extent \( Z = [4 - 11.7] \text{ km} \)
Distributed slip-rate over the fault plane
Rise time \( t_r \), variable over the fault variable
Rupture times imply non-constant rupture speed
Uniform source-time function: boxcar of width \( t_r \)
SIV forward exercise: dip-slip extended fault

- Four solutions: blue AXITRA / green COMPSYN / red TH mod / cyan SORD
SIV forward exercise: dip-slip extended fault

- Three solutions: blue AXITRA / green COMPSYN / red SORD

Corr-coeff. for top two sites
SIV forward exercise: dip-slip extended fault

- Three solutions (filtered 1 Hz): blue AXITRA / green COMPSYN / red SORD

Corr-coeff. for top two sites
SIV forward exercises: Status Summary

**Strike-slip extended-fault case:**
- Only two contributions so far, but results are encouraging
- Indication for some spatial dependency in the differences
- Correlation coefficient > 0.95
- Filtering to 1 Hz slight decreases RMS and increases corr.coeff

**Dip-slip extended-fault case:**
- Four contributions; one clearly with significant problems
- Correlation coefficients typically > 0.9, but occasionally as low as 0.5-0.6 (for a single component at a single site)
SIV benchmarks: Status Summary

- **Inv2a** has been worked on by 3 teams so far; **inv2b** not tackled
  - Kinematic ruptures, one embedded in 3D heterogeneous Earth
    - Normal-faulting M 7.0 ruptures, fault dip $45^\circ \pm 5^\circ$, strike $90^\circ$, rake $240 \pm 10^\circ$
    - Dimensions $\sim 40 \times 20 \text{km}^2$; hypocentral depth $Z = 10 \pm 1 \text{ km}$
    - Heterogeneity in slip, rupture speed, rise time; two realizations
SIV benchmarks: Inv 2a Status Summary

- (1) Team A / (2) Team B / (3) TARGET / (4) Team C
SIV benchmarks: Status Summary

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SIV benchmarks: Status Summary

- (1) Team A / (2) Team B / (3) TARGET / (4) Team C
  - Variations in RMS values factor 2-3
  - RMS on vertical component 50-100% larger (typically)
  - Model of Team C generates highest RMS values

- Cross-correlation mostly above 0.9, but as low as 0.7
- Model of Team C generates lowest cross-correlation values; model of Team A returns highest CC values

- Model of Team “best solution” so far?
SIV benchmarks: Inv 2a Status Summary

- (1) Team A / (2) Team B / (3) TARGET / (4) Team C
SIV benchmarks: Inv 2a Status Summary

- (1) Team A / (2) Team B / (3) Team C
SIV benchmarks: Inv 2 Status Summary

- Inv2a (40 data points; incl. GPS)
  - Three solutions submitted so far
  - One clearly off target; two solutions capture the main features of the target rupture
  - All three solutions fit the data well, but differences give indication to their ability reproduce the target model
  - GPS synthetics have not been used!

- Inv2b (20 data points; no GPS)
  - No solutions submitted so far
SIV online cooperation platform: Outlook

- Teleseismic benchmark: to be agreed up and defined today
- Implement overall waveform-based performance measures
  - Spatial dependencies? Frequency dependencies?
- Additional quantitative rupture-model comparisons
  - SPTC: Spatial Prediction Comparison Test (Hering & Genton, 2011)

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<td>Model 3</td>
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http://equake-rc.info

Status August 21, 2013
- 220 source models for 112 earthquakes
- Magnitude range: 4.1 – 9.2
SIV benchmarks: GF’s and inv1a
Available benchmarks: past & current

- **Green’s function test**: do we handle the forward problem correctly?
  - point-source (strike-slip / reverse) at 10 km depth, parameterized as a $1 \times 1$ km$^2$ slip patch with homogeneous slip and boxcar slip-function of duration $\tau_r = 0.2$ sec
  - The shear-modulus at the given depth results in $M_w 5.0$ ($M_0 = 3.5 \times 10^{16}$)
Available benchmarks: past & current

- **Inv2** – Two kinematic ruptures, one embedded in 3D heterogeneous Earth
  - Normal-faulting M 7.0 ruptures, fault dip 45°± 5°, strike 90°, rake 240 ± 10°
  - Dimensions ~ 40x20km²; hypocentral depth Z = 10 ± 1 km
  - Heterogeneity in slip, rupture speed, rise time; two realizations
Available benchmarks: past & current

- **Inv2** – Two kinematic ruptures, one embedded in 3D heterogeneous Earth
  - **Inv2a**: 40 near-field sites + statics at these 40 sites (synthetic GPS)
  - **Inv2b**: 20 near-field sites only
SIV benchmarks: \textbf{inv1a}

- \textbf{Inv1} – A “simple” dynamic rupture, starting from heterogeneous fault stress
  - $M \sim 6.5$, strike-slip, on $80^\circ$-dipping fault; geometry & velocity structure given
  - Near-field seismogram at 40 sites; 16 additional site for blind prediction
SIV benchmarks: **inv1a**

- **Inv1** – A “simple” dynamic rupture, starting from heterogeneous fault stress
  
  For dynamic simulations (using G. Ely’s SORD code), “constant” Dc under a linear slip-weakening was assumed (Dc increases to fault edges for smooth rupture termination)
SIV benchmarks: inv1a

- **Inv1** – A “simple” dynamic rupture, starting from heterogeneous fault stress
  - For dynamic simulations (using G. Ely’s SORD code), “constant” $D_c = 0.4 \text{ m}$ for linear slip-weakening assumed (Dc increases to fault edges for smooth rupture termination)
SIV benchmarks: **inv1a**

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SIV benchmarks: inv1a

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Time-frequency envelope misfit

Goodness of fit in envelope

Time-frequency phase misfit

Goodness of fit in phase